SEISMIC CAPACITY OF BUILDING CONSTRUCTED IN SLIP FORMED LOAD BEARING WALL PANELS

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Abstract: Constructing buildings using slip formed load bearing wall panels is becoming increasingly popular in Sri Lanka due to several advantages; low cost, environmental friendliness and rapid construction technique. These wall panels are already successfully implemented in many low rise buildings. However, the seismic capacities of these buildings have not been properly studied. Few seismic activities reported in Sri Lanka have not caused severe structural damage, but predictions can not be made as to whether this will continue to be the case in the future. This highlights the need to study the seismic capacity of buildings constructed in slip formed load bearing wall panels. This paper presents a study of the seismic capacity of the existing medium rise building.

Key words: .Pushover Analysis, Slip Formed Load Bearing Wall Panels, Rankin Failure Criterion. Finite Element Analysis

1 INTRODUCTION

The slip-formed load bearing construction method introduced in 1980‘s is very beneficial because of several advantages such as low cost, relatively rapid construction, and environmental friendliness. This method involves tamping down layers of mortar between two shutters which can be gradually raised to complete the full height of the wall panel. A combination of cement, sand and core are used to make the mortar. Different proportions (cement: sand) such as 1:8, 1:10 and 1:12 can be used to construct the wall panels in different strength and these proportions mainly govern the structural properties of the wall panels, such as Young‘s Modulus, Poisson‘s ratio, compressive strength, tensile strength, flexural strength, while the core enhance the bond between the cement and sand. These material properties were previously studied (Kulasinghe, 2000; Mendis, Kulasinghe & Jayasinghe, 2001). The behaviour of the structural members when subjected to various load combinations such as Dead+Live, Dead+Live+Wind, and Dead+Wind were studied with the appropriate partial safety factors (Dissanayake et al., 2003). Moragaspitiya & Susantha (2007) determined that the material combination of the wall panel behaves in a brittle manner. Failure of the panels can thereby be examined through Rankin failure criteria 4 and 5. Up to now, these wall panels were successfully applied to many buildings in Sri Lanka in locations including, administration buildings in the NERD CENTER, a four stories housing scheme with 16 apartments at Maligawatta, a shopping complex at Ja-ela town, and various private houses. However, these buildings were not designed for seismic loads. Seismic activities in Sri Lanka are increasing in recent years, so far without damaging structures. Despite that, predictions cannot be made as to whether this will continue to be the case in the future. This highlights the need for determining the seismic capacity of buildings constructed in slip formed load bearing wall panels. This paper presents the seismic capacity of one existing building, the four stories housing scheme with 16 apartments at Maligawatta, Sri Lanka constructed using this special wall panel construction method. Pushover analysis, which is well established in seismic engineering, is used to examine seismic capacity of the building. This study considers different material proportions.

Pushover analysis is used to determine the performance levels of buildings under seismic loadings and analysis procedure involves applying lateral loads (incremental displacements) in patterns that represent approximately the relative inertial forces generated at each floor level and pushing the structure under lateral loads towards displacements, which are larger than the threshold displacement expected at earthquakes. The pushover analysis uses a response spectrum rather than a suite of earth quake ground motions and acquires less computational time than the dynamic analysis. Additionally, this analysis is very useful for examining nonlinear analysis models and for approaching into the nonlinear performance. However, such analysis is only suitable to assess the performance of medium and low rise buildings where the first mode of vibration is dominant. The pushover analysis provides a base shear vs. roof displacement relationship and indicates the non elastic limit as well as the lateral load capacity of the structure. Yielding of various structural elements can be investigated through this relationship. Another objective of this analysis is to determine member forces as well as the global and local deformation capacity of the structure. This analysis procedure has been presented and developed over the past twenty years by various researchers and also described and recommended as a tool for design and assessment purposes (Carneiro & Almeida, 2005; Ju, 2006)

2 METHODOLOGY

One of the existing buildings built using slip-formed load bearing wall panels shown in Fig. 01.was selected for the analysis.

FIGURE 01: Side view of the four stories building situates at Maligawaththa, Sri Lanka

This building is 22.1m long, 10.0 m wide and 11.9 m height (story height = 2.6m) and consists of 16 flats. The material proportion of wall panels used in this building is 1:10 (cement : sand). A finite Element (FE) model was developed for this building. In this model, shell elements are used to model walls and slabs, while frame elements are used to model columns and beams providing appropriate sizes for elements based on the building shown in Fig. 01 using SAP2000 v.10.0 (Computers and Structures Inc., 2009). The fixed joints are implemented at the bottom of the FE model as shown in Fig. 03, assuming that the building is rigidly connected to the ground. Fig. 02 & 03 illustrate different views of the developed FE Model.

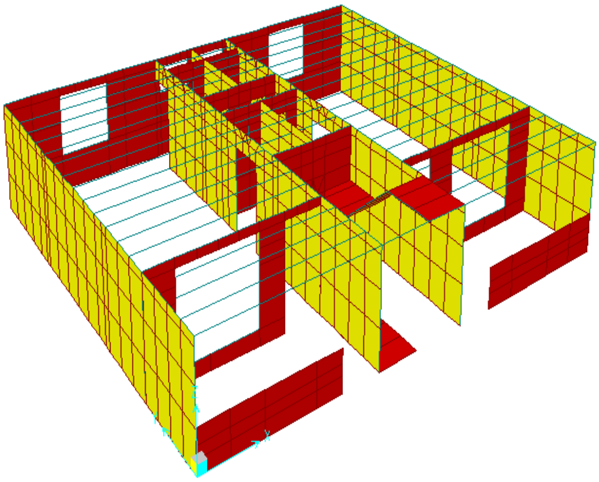

FIGURE 02: Typical arrangement of the flat of the model

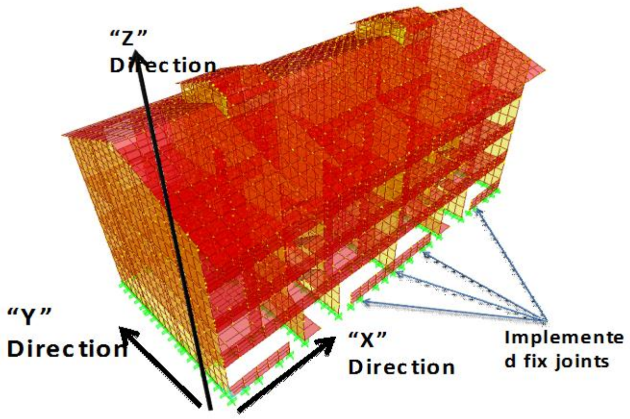

FIGURE 03: Isometric view of the model

Material properties are implemented to each element in the model based on the prototype (shown in Fig. 01). Young's Modulus and Poisson's ratio of concrete beams and columns are 30GPa and 0.18 respectively while material properties of three types of material proportions were introduced to the wall panels; (cement : sand) 1:8, 1:10 and 1:12 in order to select the best material proportion. Material properties of these proportions are tabulated in Tab. 01.

TABLE 01: Material properties of the different material proportions (Dissanayake et al., 2003)

Mix Proportion (cement : sand)	1:8	1:10	1:12
Splitting Tensile Strength (N/mm^2)	0.574	0.402	0.315
Unit weight (kN/m^3)	18.88	18.54	18.2
Young's Modulus (GPa)	10.65	6.90	5.98
Poisson's Ratio	0.12	0.15	0.17

Plastic hinges are allowed to form at floor levels in the model. The live loads tabulated in Tab. 02 are applied to the model to study the impact of the presence of live loads on the seismic capacity of the wall panels. Pushover analysis (step size=0.01mm) for the X and Y directions depicted in Fig. 03 is then performed for two load combinations such as dead load and dead+ live loads implementing the different material proportions to wall panels.

TABLE 02: Loads applied to the model

Load type	Applied Load (kN/m^2)
live load for residence area	1.5
live load for the corridors	2.0
stair cases	2.5

2.1 Rankin Failure Criterion

Morgaspitiya & Susantha (2007) determined that material of the wall panels behaviours as brittle so that Rankin failure criterion is employed to examine their capacity. Based on local coordinate system, the Rankin failure criterion of element for the x and y directions are defined through (1) and (2) as follows:

$$S1 = \frac{(Sxx + Syy)}{2} + \sqrt{\frac{(Sxx - Syy)^2}{4} + Sxy^2} \qquad (1)$$

$$S2 = \frac{(Sxx + Syy)}{2} - \sqrt{\frac{(Sxx - Syy)^2}{4} + Sxy^2} \qquad (2)$$

Where, Sxx is the x directional stress, Syy is the y directional stress and Sxy is the x and y directional stress.

For the non-failure occasion $|S1|$ and, $|S2$, where S is material failure stress.

Seismic capacities of the wall panels are determined using Rankin failure criterion and the splitting tensile strengths. In addition, variations of the base shear vs. roof displacements for the X and Y directions shown in Fig. 03 under both load combinations (dead load and dead+live loads) were examined to estimate the capacity of whole structure. The results show that variations are linear highlighting that the plastic hinges were not formed in the analysis when wall panels reach their maximum capacities. Fig. 04 only shows base shear vs. roof displacement of the analysis conducted for dead+live loads for the X direction since the results of the other analysis conducted are similar to the results in Fig. 04. These results show that the variation of the material proportion 1:10 is located in between the other two variations with material proportions 1:8 and 1:12. In addition, the roof displacement of the material proportion 1:10 (12.83mm) is higher than those of the other material proportions (11.1mm for 1:8 and 10.92mm for 1:12). This concludes that the seismic capacity of the building with wall panels in 1:10 material proportion is higher than the others.

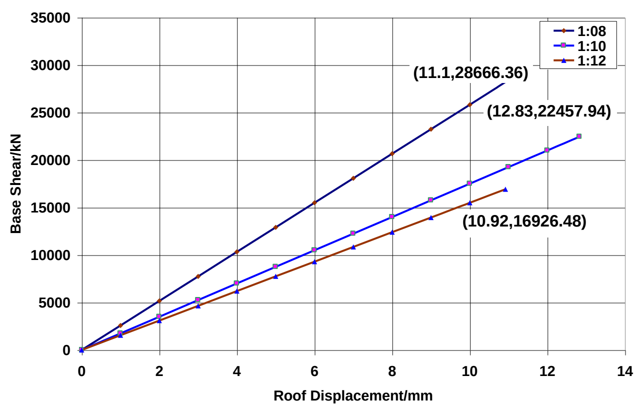

FIGURE 04: Base Shear vs. Roof Displacements for the X direction for Dead + Impose Loads

Tab. 03 demonstrates maximum roof displacements for the X and Y directions for the selected material proportions with dead+live loads. The roof displacement of the material proportion, 1:10 is higher than those of the other two proportions confirming that building with wall panels constructed in 1:10 material proportion is more vulnerable when subjected to seismic loading. Additionally, the roof displacements for the X direction is more pronounced than that of the Y direction due to that fact that the stiffness of the building in the X direction is higher than the Y direction.

TABLE 03: Maximum roof displacement for Dead and Impose Loads

Material Proportions	**Maximum Displacement (mm) at the roof level of the building (Dead Load + Live Load)**	
	X Direction	***Y Direction***
1:08	11.10	9.52
1:10	12.83	11.62
1:12	10.92	9.45

Tab. 04 depicts the roof displacement of the analysis conducted for dead load in the X and Y directions. As experienced by Tab. 03, the roof displacement for 1:10 material proportion is more pronounced that those of the other two material proportions highlighting that the building constructed with the wall panels in 1:10 material proportion is more vulnerable. In addition, the roof displacements in the X direction is higher than the Y direction due to that fact that the stiffness of the building in the X direction is higher than the Y direction.

TABLE 04: Maximum roof displacement for Dead Load

Material Proportions	**Maximum Displacement (mm) at the roof level of the building (Dead Load)**	
	X Direction	***Y Direction***
1:08	12.40	10.66
1:10	13.95	11.72
1:12	11.98	10.60

It is observed from Tab. 03 & 04 that the roof displacements for analysis conducted for dead load is higher than dead+live loads combination. This is because the seismic capacity of the building subjected to a combination of dead+live loads are low as a result of higher stresses developed in comparison to the dead load only.

3 CONCLUSION

Slip-formed load bearing wall panel construction method is increasingly popular in Sri Lanka due to its advantages such as low cost and environmental friendliness and can be rapidly constructed. A combination of cement, sand, and core are used for wall panels. The seismic capacity of the building constructed in this special wall panels was studied using three material proportions such as (cement: sand) 1:8, 1:10 and 1:12. Results highlighted that the building with wall panels constructed in 1:10 exhibit a better performance than the other two material proportions.

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